IECAG 2021

Proceedings

Effects of sand addition to heavy saline-alkali soil on the infiltration and salt leaching in Hetao Irrigation District, China†

Qingfeng Miao [1]*, Liying Zhou[1], José Manuel Gonçalves[2]*, Ruiping Li[1] and Haibin Shi [1]

[1] College of Water Conservancy and Civil Engineering, Inner Mongolia Agricultural University, Hohhot, China; imaumqf@imau.edu.cn; 1475531298@qq.com; nmglrp@163.com; shb@imau.edu.cn
[2] Instituto Politécnico de Coimbra, Escola Superior Agrária, Coimbra; LEAF - Linking Landscape, Environment, Agriculture and Food, Institute of Agronomy, University of Lisbon, Portugal;jmmg@esac.pt;
* Correspondence: imaumqf@imau.edu.cn; jmmg@esac.pt;
* Correspondence: at the 1st International Electronic Conference on Agronomy, 3–17 May 2021; Available online: https://sciforum.net/conference/IECAG2021

Abstract: Soil salinity is a matter of great economic and environmental implications. In Hetao Irrigation District, soil salinity limits crop productivity affecting about 69% of its total cultivated land, due to natural soil salinization and the salt accumulation in the soil profile caused by irrigation. The goal of the study here reported is to contribute to solving this problem through the evaluation of the technique of adding wind sand to the heavy saline-alkali soil top layer, and the analysis of the effects on the infiltration and salt leaching. The experiment, carried out on a laboratory scale, used a silty loam saline soil, 40 cm deep, with 21 g/kg of salinity, collected at Ulat Front Banner site, being the wind sand added to the 30 cm soil top layer. The infiltration tests were carried out on plastic columns with 9 cm diameter and 45 cm high, loaded with a soil and sand mixture (from 2% to 30% ratio), supplied by a constant hydraulic head. To determine the salt leaching in the soil column, soil water samples were taken for a period of 15 days. A significant increase of the infiltration rate was observed in the first infiltration hour, rising from 1 mm/h to 9 mm/h, in response to the addition of 8% and 30% of sandy particles, respectively. The effects in salt leaching were quite relevant in the top 20 cm layer; after 7 days of infiltration, a relative decrease of 35%, 55%, and 95% in soil salt were reccorded in soils with 4%, 8%, and 30% of sandy particles added, respectively. Concluding, the practice of adding sandy particles in the topsoil is a soil melioration method that allows a positive impact on soil infiltration and salt leaching. An addition of 8% of sand seems to be a good choice, as it favours an increase in salt leaching of about 55% after 7 days. These results are encouraging and appeal for field studies to assess the impact on a field-scale system, and the effects of this soil melioration on irrigation, drainage and agronomic aspects.

Keywords: soil infiltration; salt leaching; soil drainage; heavy saline-alkali soil; sand mixing; water-salt transport; Hetao Irrigation District

Citation: Lastname, F.; Lastname, F.; Lastname, F. Title. *Proceedings* **2021**, 68, x. https://doi.org/10.3390/xxxxx

Published: date

1. Introduction

The application of sand to heavy soils is a technique that could enhance the leaching of salts from the soil profile due to increased infiltration, moisture conservation and the effective porosity of soil [1]. Several studies proved that the sand added to the surface of soil benefit salt leaching [2,3], and enhance soil aggregate structure and water retention capacity [4]. Sand mixing on the surface of soil can reduce the evaporation of soil water and the accumulation of salt on the surface [1]. Therefore, the technique of addition of sand to heavy soils has a potential to increase water use and crop yield, particularly under severely saline-alkali conditions.

Hetao is located in Inner Mongolia, China, in the upper reaches of the Yellow River, with an irrigation area of about 676,000 ha. Soil salinization seriously restricts the sustainable development of Hetao agriculture, affecting about 69% of the total cultivated land area [5]. To cope with this problem several conventional measures have been implemented, like the underground drainage and the soil tillage improvement to favour the growing environment of crops and the soil salt leaching [20]. Recently, other measures have been adopted to improve salt-alkali soil, such as, mulching, aiming the soil evaporation control, or the buried straw or manure, to favour the melioration of soil ecological conditions [6]. The deep tillage to improve the soil physical and chemical properties [7] and favour deep percolation and salt leaching is also used, but the leaching time is particularly longer for the heavily saline-alkali soils.

To assess the effect of addition of sand particles to heavy saline-alkali soil on the infiltration and salt leaching, a laboratorial study with one-dimensional vertical constant water head method, was carried out in Hetao. The main objectives for this study were to analyse and quantify the influence of sand content on the soil infiltration rate and the soil salt leaching over the time, envisaging the extensive use of this technique.

2. Materials and Methods

The soil used in the experiment was collected from the 0-40 cm soil layer in the Xishanzui Farm, Ulat Front Banner, upstream of Hetao (Longitude: E 108°37′; Latitude: N 40°45′; Altitude 1118 m), being its physical properties shown in Table 1. The wind sand selected for this experiment had a volume composition of 96.7% of sand, 2.95% of silt, and 0.34% of clay, with a salt content of 1.89 g/kg. This experiment was carried out on October 2019, in the Soil Laboratory of the Inner Mongolia Agricultural University, in Hohhot.

Table 1. Soil physical characteristics of experimental site.

Soil layer (cm)	Particle composition (%)			Texture	Bulk density ($g{\cdot}cm^{-3}$)	Field capacity ($cm^3{\cdot}cm^{-3}$)	Saturation capacity ($cm^3{\cdot}cm^{-3}$)	Salinity content ($g{\cdot}kg^{-1}$)
	Sand	Silt	Clay					
0-20	26.33	60.50	13.17	silty loam	1.51	0.24	38	23.60
20-40	32.32	45.39	22.29	silty loam	1.49	0.25	39	18.43

The experimental treatments considered different ratios (x, %) of wind sand added to the original soil, identified by "Tx". Nine treatments were considered: T0, the null treatment with the original soil, and T4, T8, T12, T16, T20, T24, T28 and T30, with three repetitions each. The soil samples were mixed with sand in the 0-30 cm top layer, and the columns loaded with these mixtures. The soil layer of 30-40 cm was not modified. The infiltration process was carried out in plastic columns (Figure 1), with an internal diameter of 9 cm and 45 cm height, with a porous bottom with a filter paper to the blocking by soil particles. These columns were equipped with eight sampling holes, with 5 cm spacing, allowing soil water sampling during the experiment process. The soil column was covered with plastic film to prevent evaporation. Distilled water was added to the columns at a constant hydrostatic pressure of 5 cm, for 15 days.

In order to determine the water and salt migration in the soil column, soil water samples were collected from the sampling holes of soil the column after 3, 7, 11 and 15 days. Their electrical conductivity (EC, mS/cm) was measured at 25 °C, and then the correspondent salt content (SC, g/kg) was calculated by the equation 1.

$$SC = 3.471\ EC + 0.015. \quad (1)$$

(a) (b)

Figure 1. View of the laboratory experiment to assess the infiltration and salt leaching. (**a**) disposal of soil columns; (**b**) Column scheme; Legend: 1. bracket, 2. Marten site bottle, 3. level index, 4. valve, 5. hose, 6. plastic film, 7. column top, 8. sampling hole, 9. soil sample with added sand, 10. original soil.

3. Results

3.1. Effects of added sand on soil infiltration

Results have shown that the soil added sand had a significant effect on soil infiltration (Figure 2), with an increase of soil permeability in response to the increase of the amount of sand amended. For example, after 60 min of infiltration time, the difference of cumulative infiltration, relatively to T0, was 2, 4, 9, 26 mm, for treatments T4, T8, T16 and T30, respectively. After 300 min of infiltration time, this increase was 4, 6, 14, and 47 mm.

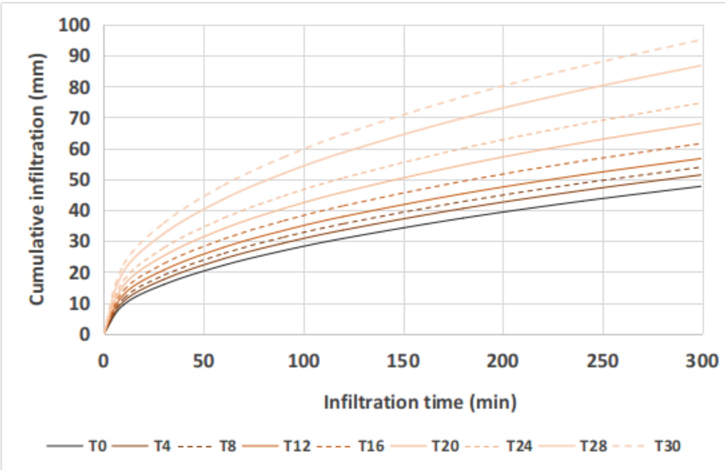

Figure 2. Cumulative infiltration curves, per treatment. Treatment, T*x*, where "*x*" represents the percentage of wind sand added to the soil.

The variation over time of the infiltration rate (Table 2) shows a direct effect of the amount of the added sand, particularly during the first 60 minutes. The differences become negligible at 300 minutes of infiltration time, from T4 to T16. These dynamic of soil infiltration rate over time reveal that at 30 min the relative rate increase compared with T0 was 13%, 33% and 100%, and at 60 min, was 9%, 18% and 82%, relatively to T8, T16 and T30, respectively. In turn, at 300 min, T8 and T16 are equal to T0, and T30 is 60% higher. These results allow concluding that the major effect of added sand occurs during the first time phase of the infiltration process. This information should be taken in consideration in the irrigation scheduling plan.

Table 2. Infiltration rates (mm/h) over time, per treatment.

Time (min)	T0	T4	T8	T12	T16	T20	T24	T28	T30
10	27	29	31	33	37	41	45	52	57
30	15	16	17	18	20	22	24	28	30
60	11	11	12	12	13	15	16	19	20
180	6	6	6	7	7	8	9	10	11
300	5	5	5	5	5	6	6	7	8

Treatment, T*x*, where "*x*" represents the percentage of wind sand added to the soil.

3.2. Effects of added sand on salt leaching

The results of the soil salt leaching (Figure 3) reveal that the process of the downward salts migration occurs particularly during the first days, and also the temporary accumulation of salts in the deeper layers. This draws attention to the sensitivity of the irrigation leaching process that should be intensive enough to allow most the leaching below the soil root zone. Treatments T16 and T30 show a higher efficiency of salt leaching bellow the 30 cm soil depth, than the other treatments (Figure 3).

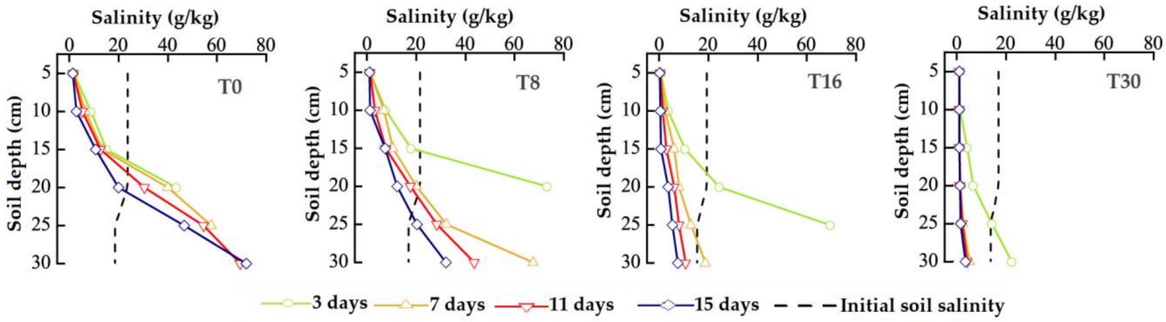

Figure 3. Dynamic distribution of soil water salinity content during 15 days leaching, of T0, T8, T16 and T30 treatments. Treatment, T*x*, where "*x*" represents the percentage of wind sand added to the soil.

On the top 20 cm layer of soil, during 15 days leaching time (Figure 4), the salt content is reduced on all treatments, and those reduction rates are variable over time. For treatments T12 to T30 this rate is higher during the first 3 days, while in the other treatments the leaching rate is almost uniform over time. On the other hand, the initial salt content reduces, compared with T0, due to the direct effect of the mixing with sand with a very low salt content.

The relative effects of added sand on infiltration and salt leaching, compared with T0 (Figure 5), on the rate and cumulative infiltration after 5 hours, and the salt leaching of 20 cm top layer during 7 days conveys that these indicators are sensitive and have a direct relationship to the added sand amount. Focusing on the effect of salt leaching, like the main target of this soil amelioration process, it shows that, even in the lower intensive treatments, T4, T8, and T12, it implied a significant salt leaching increase of 35%, 55% and 60%, respectively.

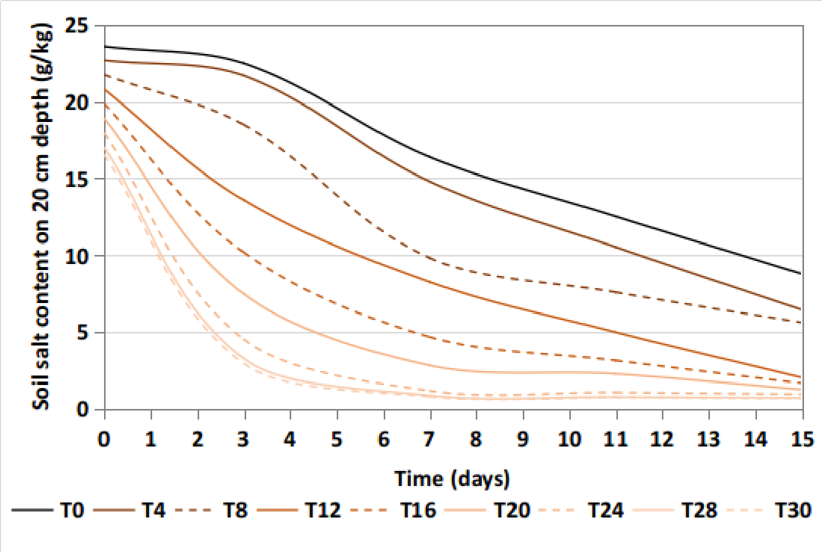

Figure 4. Soil salt content on top 20 cm layer per treatment during leaching time. Treatment, T*x*, where "*x*" represents the percentage of wind sand added to the soil.

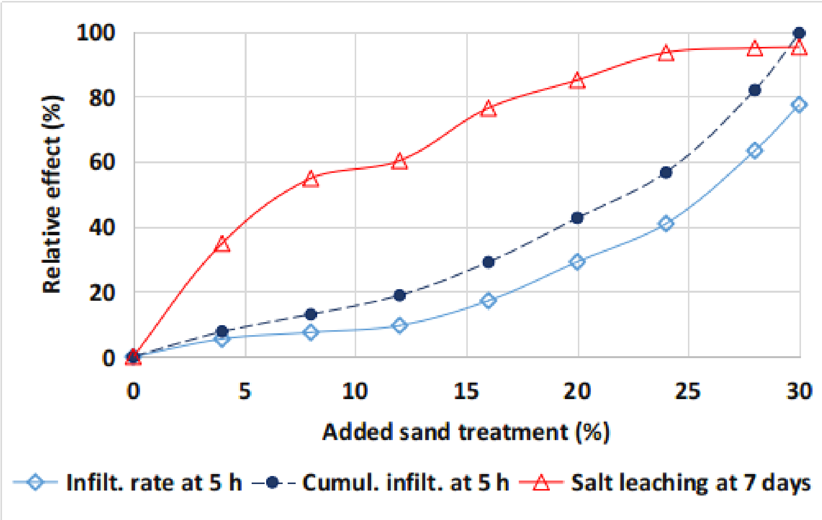

Figure 5. Relative effects of added sand on the infiltration rate, cumulative infiltration at five hours and salt leaching at Scheme 4. **Discussion and conclusions.**

Soil salinity in Hetao Irrigation District is a matter of major economic and environmental implications, which is threatening agricultural sustainability. The complexity of this issue is due to the spatial variability of soil characteristics, the relative effectiveness, and sometimes high costs, of the accomplishable solutions. Aiming to contribute to a feasible solution to this problem, an exploratory laboratory study was carried out to investigate the technique of adding wind sand to the soil top layer.

Results revealed to be promissing, as the addition of sand promotes a significant increasing effect on the infiltration rate (Table 2), especially in the first hour, being, however, incipient from the third or fifth hour onward. The infiltration rate at 1 hour, is higher 9%, 18%, and 82%, for treatments T8, T16, and T30, compared with T0. At 5 hours, the rate is equal for T0, T8 and T16, and 30% more for T30. The increase in the soil infiltration characteristics has implications on the irrigation performance, especially for surface systems, also related with the land slope and the size of the plots [8].

To be effective, salt leaching should garantee the transport of salts to layers of soil deeper than the root absorption zone. For example, below 60 cm in maize. This problem of salt migration calls attention to the question of assessing the amount of water to be infiltrated, providing, if necessary, an adequate leaching fraction, depending on the local soil salinization. This issue is correlated with the soil drainage conditions, namely the control of the groundwater level through the subsurface drainage system [9]. The analysis of the effects of added sand treatments on infiltration and salt leaching (Figure 5) leads to the conclusion, in a first approximation, that the T8 treatment (add 8% of sand on top 30 cm) is sufficient, as it favours an increase in leaching of 50%.

The technique of wind sand addition to heavy saline-alkali soil showed a significant potential to improve soil salt leaching, by increasing the infiltration rate. The practical implementation of this technique requires a deeper analysis, weighing the effects of the following factors at field level: the sand application cost, the subsurface drainage effectiveness, the management of irrigation leaching fraction, and the impact on the crop yield. The initial expectation is that the use of this technique will be limited to heavier soils and to higher yielding crops, so that the investment in the application of sand and in the improvement of drainage can have the appropriate financial benefit. Although promising, this analysis requires further experimentation in field conditions, in order to assess impacts on crop productivity and efficiency in the soil salinity control.

As a final conclusive note, encouraged by the results obtained, further studies on field trials are recommended for treatments T4, T8, and T12, as well as the assessment of their productivity, field-scale drainage system effects, soil melioration on agronomical aspects, and economical impact.

Author Contributions: Conceptualization, H.S., Q.M., J.M.G.; methodology, L.Z., Q.M. R.L.; Data analysis, Q.M., R.L., J.M.G.; writing–original draft preparation, L.Z, R.L. Q.M., J.M.G.

Funding: This research was funded by National Natural Science Foundation, grant number 52009056, 51839006, 51539005; Inner Mongolia Natural Science Foundation grant number 2019BS05015, and projects of Inner Mongolia Agricultural University, grant number NDSC2018-11; 2017XQG-4, NDYB2016-23.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Mathur, O.P.; Mathur, S.K.; Talati, N.R. Effect of addition of sand and gypsum to fine-textured salt-affected soils on the yield of cotton and jower (Sorghum) under Rajasthan Canal Command Area conditions. *Plant & Soil* **1983**; 74(1), pp. 61-65.
2. Alqahtani, M.R.A. Effect of addition of sand and soil amendments to loam and brick grit media on the growth of two turf grass species (Lolium perenne and Festuca rubra). *Journal of Applied Sciences* **2009**; 9(13), pp. 2485-2489.
3. Wenbin, L.; Xinping, L.; Haiyang, L.; et al. Effects on micro-ecological characteristics in clayey soil of tobacco area under different sand adding proportions. *J. Northwest Agricultural and Forestry* **2012**; 40(11), pp. 85-96 (in Chinese with English abstract).
4. Riquan, S.; Guixin, C.; Jun, Y.; et al. Effects of surface soil mixed with sand on water infiltration and evaporation in laboratory. Trans. of the Chinese Society of Agricultural Engineering, **2010**, 26, pp. 109-114 3 (in Chinese with English abstract).
5. Qu, Z.; Yang, X.; Huang, Y. Analysis and assessment of water-saving project of Hetao Irrigation District in Inner Mongolia. *Trans. Chin. Soc. Agric. Mach.* **2015**, 46, 70–76.
6. Jing, H. *Effects of Straw Mulching Straw of Different Cadmium Accumulate Characteristics on Nutrient Absorption and Cadmium Accumulation of Cyphomandra Betacea Seedlings.* Yaan: Sichuan Agricultural University, 2017.
7. Baozhong, Y.; Wenchao, Z.; Liguo, G. The soil ecological-environment characteristics in wheat growing season under different tillage treatments in Haihe Lowland Plain. *J. Soil and Water Conservation* **201**; 29(1), pp. 186-194.
8. Miao, Q.; Shi, H.; Gonçalves, J.M.; Pereira, L.S. Basin Irrigation Design with Multi-Criteria Analysis Focusing on Water Saving and Economic Returns: Application to Wheat in Hetao, Yellow River Basin. Water **2018**, 10, 67.
9. 20.Shi, H.; Yang, S.; Li, R.; Li, X.; Li, W.; Yan, J.; Miao, Q.; Li, Z. Soil Water and Salt Movement and Soil Salinization Control in Hetao Irrigation District: Current State and Future *Prospect. J. Irrig. Drain.* **2020**, 39, 1–17.